PCB Base Log-periodic Antenna for Mobile Communications

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Abstract: A log-periodic antenna can provide directivity and gain when operating in a wide band. The log-periodic antenna is used in many applications where wide bandwidth is required along with direct and medium gain. This research implements a sequential approach to the design and simulation of the performance of a printed log-periodic dipole antenna (LPDA) capable of operating in the 1800 MHz frequency range. The advantage of this antenna is the compactness and easy integration into planar circuits suitable for applications requiring wide bandwidth and high gain. The dimension of the designed antenna was originally calculated taking high frequency as 1885 MHz and low frequency as 1805 MHz, then modeled using HFSS-13 electromagnetic simulation to determine the effect of substrate dielectric properties on dipole width and length for element optimization. The design was verified by creating and measuring S11 and radiation diagrams. The designed antenna has a total gain of 7.9dB and a wide bandwidth.

Keywords: Printed Log-periodic Dipole Antenna, S Parameters, Bandwidth, Gain

1 Introduction

An antenna is a device for sending and receiving electromagnetic waves or it can be defined as a transducer that converts radio frequency (RF) fields into alternating current or vice versa. There are both receiving and transmission antennas for sending or receiving radio transmissions. Antennas play an important role in the operation of all radio equipment[5].

The antenna consists of two parts, a transmitter and a receiver. An antenna that transmits electromagnetic waves is called a transmitting antenna and the electromagnetic waves received simultaneously are called receiving antennas. The transmitting antenna picks up waves generated by electrical signals in a device such as a radio and converts them into waves that propagate through open space. These waves that travel in open space are called free space waves. The receiving antenna picks up free space waves and converts them into directed waves (electrical signals) compatible with cables and wires[6].

The introduction of broadband systems in communication and radar technologies required the construction of broadband antennas. Log-period antennas are often used in applications that require a wide frequency range because it is not economical and feasible to design an antenna for each frequency band. At each frequency only a small part of the whole structure is active. Electrical properties of periodic logarithmic antennas such as input impedance, pattern, direction, side lobe surface, changes in beam width with periodic logarithm of frequency. The antennas obtained from this principle are called the log-period. The length of the end-to-end dipoles, the diameter of the dipoles, and the distance of the end-to-end dipoles from the antenna apex angle (α) are related to the design constant τ. If you choose a value where τ is very close to 1, the variation across the frequency band will be small. In practice, good frequency-independent properties are observed even when τ is not very close to 1. Horn antennas and spiral antennas are other examples of broadband antennas.

A log-periodic antenna is an array of driver dipole elements designed to operate over a wide bandwidth with an acceptable degree of directivity [1, 2]. The electrical characteristics of a log-period antenna, such as input impedance, pattern, directivity, sidelobe level, and beam width fluctuations, are proportional to the logarithm of the frequency. The optional elements of this type of antenna operate with a phase shift of 180 degrees from each other. Planar log-periodic antenna is a good option to increase the antenna bandwidth.[3-6]. At a certain frequency of the process, the dipole emits almost a quarter of its wavelength and all other dipoles act passively. The active area of the antenna changes with the frequency shift. Log-periodic antennas are useful for applications such as high-frequency terrestrial television, high-frequency communications, and electromagnetic coupling measurements. This work describes the step-by-step design process for an LPDA project to operate in the 1800MHz frequency band. The initial shape was optimized for high gain and studied by an electromagnetic simulator. The antenna is fabricated and measured to validate the design.

2 Methodology

2.1 Log-periodic Antenna Design Procedure

The step-by-step open-face LPDA design procedure begins by finding τ and σ from the intersection point between the straight line σ = 0.243 τ − 0.05 called optimum σ and the desired gain. After setting the values for τ and σ, the value for the cotangent of the half apex angle α can be determined using the bellow equation; where α, τ and σ half apex angle, Design constant (scaling constant), and Spacing constant respectively[7-12].

$$tan\ \alpha = \frac{1-\tau}{4\sigma} \tag{1}$$

$$B_S = B \times B_{ar} \tag{2}$$

Where B_S is the bandwidth of the structure, B is the operating bandwidth, and B_{ar} bandwidth of the active region.

The number of required dipole elements (N) is calculated by using the,

$$N = 1 + \frac{\log B_S}{\log \frac{1}{\tau}} \tag{3}$$

The longest dipolar element can be determined by substituting the lowest frequency (fL) using equation (4). The distance between the longest dipole element and the adjacent dipole elements can be calculated from Equation (5). The length and distance of the remaining elements are calculated using Equations (6) and (7), respectively.

$$l_1 = \frac{c}{2f_L} \tag{4}$$

$$d_{12} = \frac{(l_1 - l_2)}{2} cot\ \alpha \tag{5}$$

$$l_{n+1} = \tau\, l_n \tag{6}$$

$$d_{n+1} = \tau\, d_n \tag{7}$$

where C, $f_{L,}d_{12}$ are velocity of the space, lowest frequency and spacing between the first and second elements respectively.

The width of the dipoles can be calculated by considering the matching impedance as shown in equation (8). By using equation (9) the successive widths can be calculated.

$$Z_0 = 120 \times [\ln \frac{L_n}{a} - 2.25] \tag{8}$$

$$W_n = \Pi \times a \tag{9}$$

$$W_n = \tau\, W_{n+1} \tag{10}$$

Here $Z_{0,}L_n$, a and W_n are respectively matching impedance, half length of the largest dipole radius of the dipole, and width of the dipole. For this work, the LPDA is designed to cover the high-frequency 1800 MHz frequency. Therefore, as described above in the step-by-step design process, the antenna parameters σ = 0.16, τ = 0.93, Bar = 1.446 ×106 Hz, Bs = 1.5096×106 Hz, N = 7. The length and spacing between the dipoles calculated from the above equations are the initial dimensions that need to be modeled in simulations to improve and study antenna performance.

2.2 Simulation Setup

The software used to model and simulate the LPDA antenna is HFSS 13 software. HFSS-13 is a full-wave electromagnetic simulator based on the method of moments. Analysis of three-dimensional and multilayer structures of common shapes can be carried by using the HFSS-13. It is widely used in the design of MICs, RFICs, patch antennas, wire antennas and other RF/wireless antennas. it used to calculate and plot 11 S parameters, VSWR, current distribution and radiation pattern. An evaluation version of the program was used to obtain the results of this study.

The simulation first starts using the length, width and pitch positions of the dipole elements in the case of a 7 element LPDA.

LPDA sizes were originally designed for clearance, but due to the influence of dielectric lines, the dimensions may vary slightly when used on a PCB. It is very difficult to determine the conductor width of the feeder element and the dipole element so that the characteristic impedance is 50 Ω. Therefore, to verify the designed antenna and investigate the antenna performance, a sample structure was performed through simulation.

2.3 Fabricated Antenna Design

In this work, an economical FR-4 PCB substrate whose dielectric constant and loss tangent are respectively 1.4 and 0.002 is used. The above simulated antenna was fabricated using the normal PCB making method as shown in Fig.1.

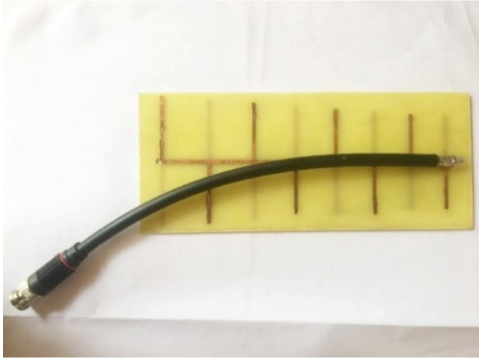

Fig.1 Fabricated Antenna Design on Printed Circuit Board with the Soldered Antenna Connector

Spectrum Analyzer was used to validate whether it was tuned to the correct frequency. As shown in Fig.2 within 1700-1900MHz frequency the peaks can be obtained.

3 Results and Discussion

3.1 Simulation Results

Fig.3 shows the Frequency vs. VSWR curve for the designed antenna. VSWR, voltage standing wave

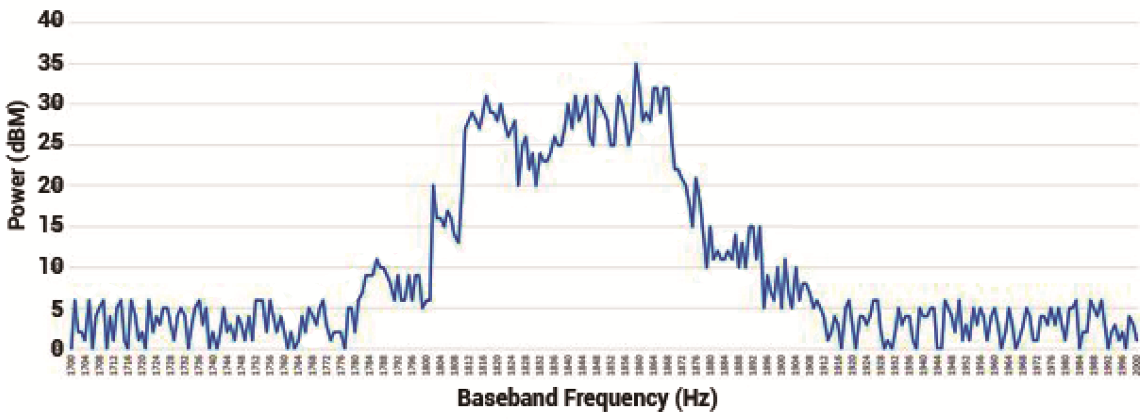

Fig.2 Data Obtained from the Spectrum Analyzer: Peaks around 1700-1900MHz Frequency Range

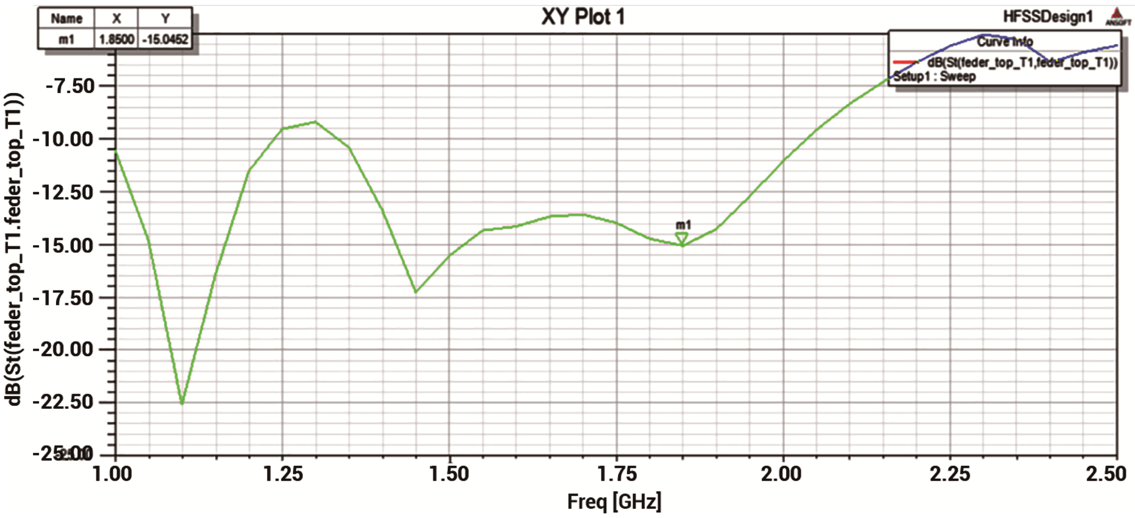

Fig.3 Frequency vs VSWR Curve for the Designed Antenna

ratio, is a function of reflection coefficient, Γ, which describes the power reflected from the antenna. VSWR for antennas is always real and positive. It is clear that the smaller the VSWR and the lower the reflection coefficient, the better the antenna matches the transmission line and the more power the antenna receives. At least VSWR 1.0 is ideal and no power is reflected from the antenna. VSWR is the amount of power that reaches the antenna. This does not mean that the antenna exits all the power it receives. Therefore, VSWR measures radiation potential. A low VSWR means that the antenna matches well, but does not mean that a given power is also radiated. The power supplied to the antenna is radiated.

Fig.4 and Fig.5 are the graphical representation of the radiation properties of the antenna as a function of space. That is, the antenna's pattern describes how the antenna radiates energy out into space (or how it receives energy). The pattern of the mentioned figures clearly indicates directional radiation. Therefore, the gain and the signal strength are relatively higher than the traditional antennas such as Yagi.

As shown in Fig.5, the initial dimensions were calculated under free space conditions, then the gain was optimized with the HFSS-13 simulator to get 7.9 dB, so the dimensions of some dipoles have deviated from its calculated value. This can be occurred due to several factors such as difference in the spacing of the

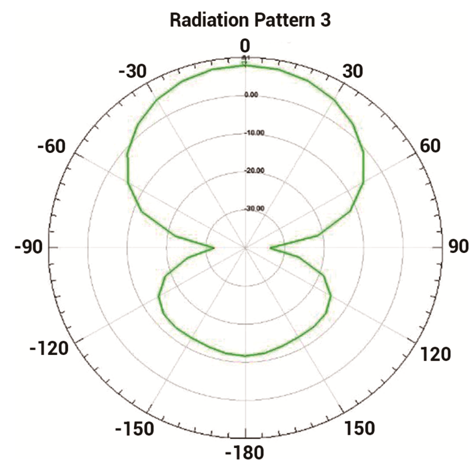

Fig.4 The Radiation Patterns for Directional Gain Which Represents the Gain for One Direction Using HFSS Software

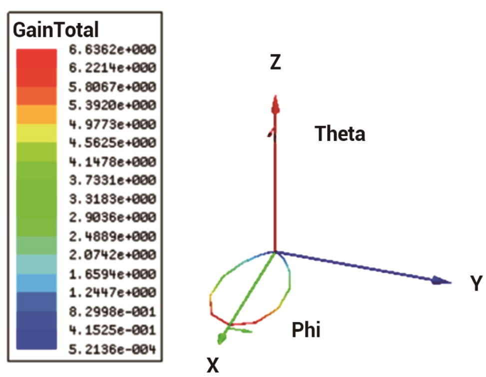

Fig.5 The Radiation Patterns for Total Gain Which Represents the Gain for All the Directions Using HFSS Software

created PCB strips and reduced surface quality of the manually printed strips. These defects can be the evidence for the observed radiation deviate. Fig.4 and Fig.6 illustrate the directional gain and the 3D polar plot for the designed antenna. In this design, the LPDA antenna was fabricated using FR-4 substrate. FR4 epoxy glass substrates are the material of choice for most PCB applications. The material is very low cost and has excellent mechanical properties, making it ideal for a wide range of electronic component applications.

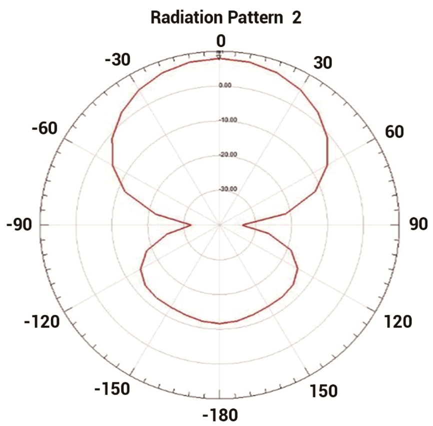

Fig.6 This Shows the 3D Polar Plot for Total Gain

Further, the fabricated pattern can be micro sized using automated CNC technologies. The chemical etching process can be improved with analytical instruments and chemicals to improve the strip quality while maintaining a very small size.

The same design can be improved to the frequency range of 2GHz with relevant modifications. The wide frequency band-based antenna design will be a good candidate for many applications. The proper matching of the impedance of such a device will be further studied in future research works.

4 Conclusions

The concept of Log-Periodic Dipole Array antenna has been studied and have seen that for wideband application log-periodic antennas are used. Based on the given specifications and assumed values of Scale Factor (τ) and spacing factor (σ), a log-periodic dipole array antenna was designed. In this paper, a log-periodic dipole antenna is designed and simulated using an HFSS simulator covering a frequency band of 1800MHz with the required high gain and wide bandwidth. In HFSS, the antenna was drawn using calculated parameters. The primary goal was to improve the performance of existing antennas, and this goal was theoretically achieved by designing a wide band wide gain dipole antenna (LPDA).

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